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COST DIFFERENCES IN PUBLIC AND PRIVATE SHIPYARDS

Marianne Lowes

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REPORT DOCUMENTATION PAGE

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14

1. REPORT NUMBER: CRC-442
2. GOVT ACCESSION NO.: AD-A102 877
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): 6 Cost and Efficiency Differences in Public and Private Shipyards.
5. TYPE OF REPORT & PERIOD COVERED
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): 10 Marianne Bowes
8. CONTRACT OR GRANT NUMBER(s): 15 N00014-79-C-0448
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Center for Naval Analyses, 2000 N. Beauregard Street, Alexandria, Virginia 22311
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 12) 34
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Ass't Secretary of Defense Manpower Reserve Affairs & Logistics, Special Proj. Washington, D.C. 20301
12. REPORT DATE: 11 January 1981
13. NUMBER OF PAGES: 27
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release, distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

9

18. SUPPLEMENTARY NOTES: The material in this research contribution was prepared under contract N00014-79-C-0448 with the Department of Defense. The views expressed in this paper are those of the author and not necessarily those of the Department of Defense.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number): coefficients, costs, maintenance, naval shore facilities, naval vessels, nuclear powered ships, regression analysis, repair, salaries, shipyards, submarines

20. ABSTRACT (Continue on reverse side if necessary and identify by block number): The repair of naval vessels is one type of production which is performed in both the public and private sector. Input prices are not the same in naval and private shipyards; in particular, wages are higher and the cost of capital is lower in naval shipyards. In this paper, an attempt was made to determine (a) how these differences in factor prices affect the relative cost of overhauls, and (b) some possible reasons for differences in overhaul costs.

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S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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20 First, a cost function was estimated, using data on overhauls of the Sturgeon class of nuclear attack submarines. The regression coefficients were then used to predict costs in public and private yards holding the relevant variables constant. The results support the hypothesis that, for the type of work studied, production costs were higher in naval shipyards than in private shipyards.

Among the likely reasons for the difference in production costs are (a) higher wages and (b) lower efficiency in naval shipyards. Further work is needed to determine whether there is also a difference in overhaul quality.

The time spent in overhaul is important because of its implications for readiness. We found that overhauls in private shipyards took significantly longer than those in naval yards. When determining where to assign overhauls, the Navy must weigh this difference in time costs against the difference in production costs.

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CRC 442 / January 1981

COST DIFFERENCES IN PUBLIC AND PRIVATE SHIPYARDS

Marianne Bowes

Prepared under contract N00014-79-C-0448 for:

Office of Assistant Secretary of Defense
Manpower Reserve Affairs & Logistics
Special Projects
Washington, D.C. 20301

Points of view or opinions stated in this paper do not necessarily represent the opinion of the Department of Defense.

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INTRODUCTION

A major difference in the nature of production in the public and private sectors is the lack of the profit motive in the public sector. Government agencies often have no competition from either other agencies or private firms. In addition, there is little possibility of an agency being forced out of business if it produces inefficiently.

For this reason, if we could observe public and private firms producing the same type of output, we might expect production costs to be higher for the public firms. Such a difference in costs could arise because of differences in the prices paid to factors of production and/or in the use of these factors. A difference in factor prices does not in itself indicate inefficiency in production. Rather, inefficiency is said to exist if, for given factor prices, (a) the maximum achievable output is not attained with the inputs used (technical inefficiency) or (b) inputs are used in the wrong proportions (allocative inefficiency).

The preceding discussion implies that there are at least two questions of interest in a comparison of production costs for public and private firms:

(1) Do the costs of production differ?

(2) If so, why? That is, are the differences in production costs due to differences in factor prices, differences in efficiency, or other reasons?

In this paper, we will attempt to answer these questions for a particular type of production, namely the production of overhauls of nuclear submarines in public and private shipyards.

The paper is organized as follows. In the next section, the problem of comparing production costs in public and private shipyards is discussed in more detail. The third section describes the data, the fourth the methodology, and the fifth the results of this comparison.

THE PROBLEM

The choice of shipyards as the type of firm for which to compare production costs has two advantages. First, unlike the output of other government agencies--e.g., defense, education, regulation--the output of naval shipyards is tangible and, thus, relatively easy to quantify. Second, shipbuilding and repairing is one of the few types of production which occurs in both public and private firms. New construction and overhaul of naval vessels is done in public and private shipyards; however, the work is not evenly divided. At one time, ships were built in both types of yard, but since 1967 no new construction has been assigned to naval yards. In contrast, most overhaul work is done in naval yards.

In order to understand the motives of naval shipyard managers, a brief description of the industry is necessary. Currently, there are eight naval shipyards, four on each coast (see table 1). In the private sector, the shipbuilding and repairing industry (SIC 3731) consists of a few large firms and many smaller ones. Eleven yards are presently considered capable of undertaking major Navy new construction work; these are listed in table 1. As of February 1, 1978, these eleven yards accounted for about 63 percent of total private shipyard employment ([21], pp. 18-19). Only three private yards--Newport News, Ingalls, and Electric Boat--are currently qualified to handle nuclear materials.

The division of naval new construction and repair work between public and private shipyards appears to be based primarily on political rather than economic considerations. Shipbuilding is felt to be an industry that is important for national security, and funds are allocated so that both public and private shipyards can maintain a state of readiness. Congress is not, however, completely insensitive to differences in construction cost, as will be seen below.

Historically, it has been felt that public shipyards have higher production costs than private yards. For example, during the debate on the Vinson-Trammell Act of 1934,* it was generally acknowledged that the costs of building ships were higher in naval shipyards, partly because these yards were oriented toward repairing rather than building ships

*The Vinson-Trammell Act provides that the first and each succeeding alternate vessel in each class of naval ships shall be built in naval shipyards, except if this is inconsistent with the public interest. Since 1948, the public interest clause has been exercised every year.

and partly because of "the relative inflexibility and higher pay of Civil Service personnel." Since that time, higher public shipyard costs have been an important factor in the transfer of naval work from the public to the private sector ([3], pp. I-5, I-7). For example, in reference to the FY 1974 Navy shipbuilding program, it was reported: "Funds were also cut from the DLG conversions on the grounds that they could be saved by having the work done in private yards instead of naval shipyards where such jobs have normally been done." ([2], p. 71).

TABLE 1

LOCATION OF MAJOR SHIPYARDS

Coast	Naval	Private
Atlantic	Portsmouth, NH	Bath (Bath, ME) Electric Boat (Groton, CT)
	Philadelphia, PA	Quincy (Quincy, MA)
	Norfolk, VA	Bethlehem (Sparrows Point, MD)
	Charleston, SC	Newport News (Newport News, VA)
Pacific	Puget Sound, WA	Lockheed (Seattle, WA)
	Mare Island, CA	Todd (Seattle, WA)
	Long Beach, CA	Todd (San Pedro, CA)
	Pearl Harbor, HI	National Steel (San Diego, CA)
Gulf		Avondale (Avondale, LA) Ingalls (Pascagoula, MS)

In 1972, Booz-Allen compared the costs of comparable ship work, including new construction, conversions, and overhauls in public and private yards for the fiscal years 1966-71. They found that the cost of new construction was, on average, about 35 percent higher in naval shipyards. An update of their study to 1977 indicated that although some convergence in cost had occurred, the cost of new ship construction remained significantly higher in naval shipyards. In both studies, higher wage rates and fringe benefits for naval shipyard employees were found to contribute significantly to the difference in cost ([3], p. I-7, Chapter VI).

Thus, in our investigation of overhauls of nuclear submarines, we might expect to find both production costs and the price of labor to be higher in naval shipyards than in private ones. However, as mentioned earlier, such a conclusion would not necessarily indicate inefficiency on the part of naval shipyards. Although competition between public and private shipyards is not as intense as it would be if they were directly bidding against one another, the desire to lower production costs and increase productivity does appear to influence naval shipyard managers. In Naval Engineers Journal, for example, new management techniques are advocated "with a view toward increasing productivity ..., lowering costs, improving quality, and getting ships out earlier." ([24], p. 60).* It therefore appears that naval shipyards make at least some attempt to minimize their costs of production. Whether or not they succeed is one of the questions we shall attempt to answer in the empirical work.

*See also [12], [16].

THE DATA

Ideally, the investigation of production cost differences in public and private shipyards should be based on data showing public and private yards working on the same type of ship. Data on output (Q)--e.g., the number of ships constructed or repaired--input quantities--the amount of capital (K), labor (L), and materials (M) used--and input prices (p_K, p_L, p_M), for each shipyard in each year is desired.

THE BASIC DATA SET

Because no new construction has been assigned to naval shipyards since 1967, there are no recent classes of ship which have been built by both public and private shipyards. Overhauls of nuclear submarines have, however, been done by both types of yard. The data which we have used concerns overhauls of the Sturgeon class of nuclear attack submarines (SSN 637) between 1971 and 1979.* 61 overhauls were performed during this time, 54 by naval shipyards and 7 by private yards. (See table 2.)

As indicated in table 2, there are three types of overhaul. Regular overhauls take, on average, 12 months and include both repair and alteration work. Refueling overhauls last about 18 months; in addition to the type of work done during regular overhauls, they include replacement of the nuclear core which powers the submarine. Selected restricted availabilities (SRAs) involve only repair work and generally last about 2 months.

The unit of observation in our data is an overhaul. For each overhaul, we have:

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*The basic data was obtained from PERA (Planning and Engineering for Repairs and Alterations), which is part of the Naval Sea Systems Command (NAVSEA). We would like to thank Dr. John Berning of the Institute of Naval Studies for providing us with this data and with background information for the study. The PERA data was used rather than the Litton data discussed in the proposal for several reasons. For example, while the Litton data is very detailed, it only pertains to one shipyard and, thus, in itself provides no opportunity for comparison between public and private shipyards. In a more complete study of overhaul production costs, it might be possible to use the Litton data to supplement the analysis of more aggregate data.

- total cost, $C = p_K K + p_L L + p_M M$
- material cost, $p_M M$
- man-days, L
- date, location, and type of overhaul
- age of the submarine after overhaul.

The data described above does not include a complete set of information on either input prices or input quantities. In order to analyze production costs, however, it is necessary to have at least one of these sets of information. Since it was felt that input prices could more easily be constructed from other data sources than input quantities could, this was the approach taken. The results are described in the following section.

TABLE 2

NUMBER OF OVERHAULS BY SHIPYARD AND TYPE

Shipyard	Regular	Refueling	SRA
Norfolk	8	0	5
Charleston	1	3	8
Portsmouth	7	1	4
Puget Sound	6	4	1
Pearl Harbor	2	0	2
Mare Island	0	1	1
Electric Boat	3	1	0
Ingalls	1	0	0
Newport News	0	2	0
Total	28	12	21

INPUT PRICE DATA

Choosing measures for capital, labor, and material prices was an important but difficult part of the empirical investigation. Ultimately, the answers to the questions posed at the beginning of this paper depend on the input prices used.

For each of the three inputs, price data for the 61 overhauls was developed as follows. First, a monthly or quarterly time series was constructed for 1971-79. The input price for a given overhaul was then computed as a weighted average of the prices prevailing during the months when that overhaul took place. The construction of the time series for p_K, p_L, and p_M is discussed below.

Capital Price

The appropriate price for capital is the user cost of capital, that is, the price of the flow of services from the capital stock. The simplest measure of this cost is r, the interest rate on borrowed funds. If we think of r as including a risk premium, then a priori we would expect r to be higher for private shipyards than for public ones. Because the Federal Government is the most stable "firm" in the economy, investors should be willing to accept a lower rate of return from the public sector than from private firms.

A more precise but more complicated formula for p_K was developed by Hall and Jorgenson [8]. If a firm maximizes the discounted sum of its profits, then its user cost of capital (in value terms) is

$$c = [q(r+\delta) - \dot{q}]\ (1-k-uz)/(1-u), \quad \text{where}$$

q = the price of capital goods

δ = the rate of replacement of the capital stock (assumed to equal the depreciation rate)

$\dot{q}$ = dq/dt

k = the investment tax credit rate

u = the corporate profits tax rate

z = the present value of depreciation (for tax purposes) per dollar of original cost.

Assuming that q and δ are the same for public and private shipyards, c will differ for the two types of yards for two reasons. First, as noted above we expect r to be higher for private shipyards. Second, the "tax factor," $(1-k-uz)/(1-u)$, will differ between yards. Public firms are not subject to tax laws, so for public shipyards, the tax factor equals 1. For private shipyards, this factor may be greater or less than 1, depending on the values taken by k, u, and z.

Both r and c have been used to represent p_K in previous empirical studies (see, for example, the studies in [7]). We have used them as alternate measures of the price of capital. Because of the complexity of the formula for c and the compounding of measurement errors which it may involve, we have some preference for r as a measure of the capital input price. The data sources for r, q, δ, k, u, and z are given in the appendix.

Wages

Before describing the wage data used, it might be of interest to describe the wage-setting process in public and private shipyards. Except for management, employees in naval shipyards are not members of the Navy. Rather, these workers, like other blue-collar employees of the Federal Government, are paid according to the Coordinated Federal Wage System (CFWS). Under this system, all federal agencies within a given geographical area pay the same wages, but wage rates may differ across regions. Wages within a region are determined by annual surveys of the prevailing wages in that area. The Coordinated Federal Wage System includes separate wage schedules for nonsupervisory, leader, and supervisory employees. In the first two, there are 15 grades with 5 steps per grade; in the third, there are 19 grades with 5 steps per grade.

According to a BLS survey of wages in shipbuilding and repairing, in September 1976 a majority of production workers in private shipyards were covered by collective bargaining agreements ([20], p. 1). Unions also exist in public shipyards; they are active participants in the federal wage-setting process [6].

The ideal measure of the price of labor would be total compensation (wages plus the value of fringe benefits) per man-hour. Since information on fringe benefits is generally not available, we must use the hourly wage rate instead. However, a problem was encountered in that the data on hourly wages that is most readily available is not strictly comparable between public and private shipyards. For public yards, the data consists of copies of the CFWS wage schedules for each shipyard in each year. We also have information on the correspondence between occupations and grades for the WG (nonsupervisory) schedule ([20], p. 21). For private shipyards, in contrast, the primary data is average hourly earnings for production workers in SIC 3731, available for the nation as a whole in [19] and by region in [23]. This average is calculated as total payroll divided by total man-hours worked.

The wage data for private shipyards differs from that for public yards in two respects. First, the former includes premium pay for overtime, weekends, holidays, and late shifts, but the latter does not. More importantly, while we have individual wage rates for public shipyards, all we have for private shipyards is a weighted average of wage rates over all occupations and tenure levels. That is (ignoring the first difference) if w_{ij} = the hourly wage rate for a worker with tenure j in occupation i and MH_{ij} = total man-hours worked by employees with tenure j in occupation i, then for public shipyards, we have a matrix of w_{ij}'s, but for private yards, we have the single value $\overline{w} = \sum_j \sum_i MH_{ij} w_{ij} / \sum_j \sum_i MH_{ij}$.

The data for public shipyards is closer to the ideal measure of the price of labor than is the data for private shipyards. This is because the former represents the exogenous set of wage rates faced by public shipyard managers, while the latter is to some extent endogenous since it reflects private shipyard managers' employment of various kinds of labor.

Given this problem it was necessary to adjust the private shipyard wage data in some way to make it more comparable to the public yard data. In the BLS survey of wages in shipbuilding [20], distributions of straight-time hourly earnings by occupation and geographical region for September 1976 were reported. Assuming that the observed distribution of earnings is a good representation of the possible range of wage rates, we may interpret the survey information as a set of regional wage schedules for 1976. Similar schedules for the other years of the sample period were then computed. This was done by assuming that the ratio of the wage rate for a particular occupation to the average wage in a given region was the same in the other years as it was in 1976.

Once we had these "wage-schedules" for private shipyards, one problem remained: which wage, or wages, to use as the price of labor in the empirical work. The wages in a wage schedule are too highly related to one another for all of them to be included in a regression equation. Accordingly, it was decided to use the wage rate for one typical shipyard occupation, namely, shipfitters. Moreover, since we did not know exactly how wages vary with tenure in private shipyards, it was decided to use the lowest, i.e., zero-tenure, wage. Thus, the starting wage rate for shipfitters, taken from Step 1 of Grade 10 in the WG schedule for public shipyards and estimated from average hourly earnings for private shipyards, was the measure of the price of labor in the empirical work.

Material Price

While it might be expected that the prices of capital and labor differ in public and private shipyards, there is no strong evidence that material prices also differ. Accordingly, the same material price index was used for both types of yard.

The index we used was a composite index based on the Producer Price Indexes for iron and steel, general purpose machinery and equipment, and electrical machinery and equipment. The percentage change in the composite index was calculated using weights of 45 percent, 40 percent, and 15 percent, respectively, for the percentage changes in the three PPIs. According to [5b], p. 803: "These weights are used by both MarAd and the Department of the Navy for calculating material cost indexes ..."

COMPARISON OF INPUT PRICES

The ideal way to analyze factor price differences in naval and private shipyards would be to regress the price for a factor on the characteristics of that factor for each type of yard. For example, in the case of labor, we might regress the hourly wage rate on the skill and experience levels associated with that wage rate. Statistical tests could then be used to determine whether naval shipyards pay the same amount for increases in skill or tenure as private shipyards do. We do not have enough information on input prices to do such a rigorous analysis. We can, however, make some simple comparisons.

Table 3 lists ranges of hourly wages in naval and private shipyards for 26 occupations in September 1976; the information is taken from [20]. The occupations are listed roughly in order of skill. No strong conclusions can be drawn from this table. For a given occupation and coast, the ranges of wage rates in public and private yards always overlap to some extent. For the Atlantic coast, starting wages in naval shipyards are higher than the lowest observed wages in private yards except for the least skilled jobs. A similar pattern can be seen for the Pacific coast, although the conclusion is less strong here.

In table 4, annual average values of the wage data used in the empirical work are given. Bearing in mind the limitations of this data--i.e., starting wages for shipfitters in private yards are estimated rather than observed--we note that the wage rates are uniformly lower in private shipyards.

Turning from labor to capital, table 5 presents annual averages of the capital price data used in the empirical work. As expected, r is

TABLE 3

WAGES IN PUBLIC AND PRIVATE SHIPYARDS, SEPTEMBER 1976

	Range of hourly wage rates in Naval shipyards		Range of straight-time hourly earnings in private shipyards	
Occupation	Atlantic	Pacific	Atlantic	Pacific
Janitor	3.31-5.42	4.39-5.97	3.60-6.00	3.60-7.20
Laborer	3.55-5.42	4.63-5.97	3.80-6.20	---
Equipment cleaner	4.10-6.04	5.10-6.76	4.60-7.40	5.40-7.60
Forklift operator	4.39-6.04	5.34-6.76	---	5.40-7.60
Helper	4.39-6.04	5.34-6.76	4.00-6.20	---
Truck driver	4.68-6.25	5.58-7.09	4.40-6.40	5.40-8.00
Painter	4.98-6.50	5.81-7.41	4.20-8.00	5.60-7.80
Bridge crane operator	4.98-7.29	5.81-8.05	4.80-8.00	7.40-7.80
Hand welder, class B	5.25-6.89	6.05-7.73	5.00-6.40	5.60-7.60
Machine welder	5.25-7.69	6.05-8.37	5.00-8.00	5.40-7.60
Carpenter	5.50-7.29	6.29-8.05	5.00-6.60	---
Machine-tool operator	5.50-7.29	6.29-8.05	4.80-5.60	---
Boom crane operator	5.50-8.10	6.29-8.00	5.20-6.80	6.00-8.00
Boilermaker	5.76-7.69	6.53-8.37	5.00-8.00	5.60-7.60
Marine electrician	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Maintenance electrician	5.76-7.69	6.53-8.37	4.80-6.80	---
Maintenance machinist	5.76-7.69	6.53-8.37	5.00-6.80	5.60-7.60
Mechanic	5.76-7.69	6.53-8.37	4.80-6.80	---
Marine pipefitter	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Maintenance pipefitter	5.76-7.69	6.53-8.37	4.80-6.80	---
Rigger	5.76-7.69	6.53-8.37	4.80-6.80	5.60-7.60
Sheet-metal worker	5.76-7.69	6.53-8.37	---	5.60-7.60
Shipfitter	5.76-7.69	6.53-8.37	4.80-8.00	5.60-7.60
Shipwright	5.76-7.69	6.53-8.37	4.80-6.60	5.60-8.00
Hand welder class A	5.76-7.69	6.53-8.37	5.20-8.00	7.40-7.80
Electronics technician	6.01-8.50	6.76-9.00	5.40-6.80	7.60-8.00

TABLE 4

ESTIMATED STARTING WAGES FOR SHIPFITTERS IN PUBLIC AND PRIVATE SHIPYARDS, 1972-79

	Public shipyards						Private shipyards		
	Norfolk	Charleston	Portsmouth	Puget Sound	Pearl Harbor	Mare Island	Electric Boat	Ingalls	Newport News
1972	4.07	4.25	4.20	4.70	5.17	5.05	3.65	3.05	3.70
1973	4.32	4.51	4.38	4.97	5.46	5.33	3.94	3.19	3.83
1974	4.73	5.19	4.70	5.46	6.01	5.88	4.15	3.43	4.05
1975	5.17	5.86	5.41	6.09	6.59	6.54	4.47	3.74	4.60
1976	5.58	6.37	5.92	6.75	7.32	7.27	4.94	4.05	4.74
1977	5.96	6.73	6.49	7.34	8.05	7.90	5.32	4.34	4.94
1978	6.35	7.32	6.86	7.96	8.71	8.59	5.79	4.92	5.36
1979	6.72	7.79	7.28	8.44	9.37	9.12	6.36	5.26	6.21

consistently higher for the private yards; in addition, c, the user cost of capital, is also consistently higher. Regarding the tax factor, the values of k, u, and z during the 1970s were such that $(1-k-uz)/(1-u)>1$, widening the gap in the user cost of capital between public and private yards.

TABLE 5

CAPITAL PRICES IN PUBLIC AND PRIVATE SHIPYARDS, 1971-78

	Naval shipyards		Private shipyards	
	r(%)	c	r(%)	c
1971	5.70	.182	7.57	.248
1972	5.54	.189	7.35	.241
1973	6.21	.196	7.60	.245
1974	6.88	.193	8.78	.257
1975	6.96	.245	9.25	.322
1976	6.79	.272	8.84	.349
1977	7.53	.287	8.28	.339
1978	8.40	.321	8.90	.380

Having discussed the data, we turn now to the methodology used to compare production costs and efficiency in public and private shipyards.

METHODOLOGY

There are a number of ways in which the question "do production costs differ?" could be answered using our data. The simplest way would be to compute the average cost of an overhaul in each type of shipyard. This is done in part A of table 6. Part A indicates that refueling overhauls cost, on average, about 65 percent more than regular overhauls and about 16 times as much as SRA's. It also shows that, for our sample, regular overhauls cost about 18 percent more and refueling overhauls 6 percent more in public shipyards than in private ones.

TABLE 6

AVERAGE VALUES PER OVERHAUL

	Regular	Refueling	SRA
A. Total Cost (1972 $)[a]			
Public	16,857,141	27,617,194	1,672,426
Private	14,287,437	25,975,177	---
B. Material Cost (1972 $)[b]			
Public	2,015,609	2,745,777	203,575
Private	2,104,714	3,425,244	---
C. Man-days			
Public	144,173	243,146	14,466
Private	151,133	237,652	---

Deflators:

[a] Implicit Price Deflator for DoD Purchases of Ship Construction, from [17].

[b] Material Price Index as described in the previous section.

We are, of course, interested in determining not only whether production costs differ but also why they differ. Part B of table 6 indicates that the higher production costs of naval shipyards were not due to higher material costs. Since we do not know the average cost of a man-day, Part C does not tell us whether public shipyards had higher labor costs than private shipyards. It does show, however, that the average quantity of labor used per overhaul was not substantially different in the two types of yards.

Although useful as a starting point, comparisons like those in table 6 do not tell the whole story. There are a number of variables besides type of overhaul and type of shipyard which might be expected to influence the cost of an overhaul. In our attempt to determine whether production costs differ in public and private shipyards, we will want to hold some of these other variables constant. In order to be able to do this, we used regression analysis to estimate a cost function. In the following sections, we will discuss the estimation procedure in detail: first, the variables included in the regression equations and second, the functional form chosen for the equations.

VARIABLES

In its simplest form, a cost function gives production cost as a function of input prices and output: $C = f(p_M, p_L, p_K, Q)$* There were several other variables which we felt were relevant to our analysis:

A, the age of the submarine;

X, the number of overhauls previously done in the shipyard;

T, time (the year in which the overhaul began);

Y, a dummy variable for the type of shipyard.

The reasons for including these variables will be explained below.

We expect C to be an increasing function of input prices and output. Moreover, the cost function should be homogeneous of degree 1 in input prices; that is, if all input prices increase by 1 percent,

*The economic interpretation of a cost function is that it represents the minimum cost of producing a given amount of output. Theoretically, we expect a firm to minimize cost (or maximize profit) over the entire range of its operations. This means that the cost function for a shipyard should include data for all types of shipyard output, e.g., new ship construction as well as overhauls. We did not have data on activities other than SSN overhauls for the shipyards in our sample; accordingly, the cost functions we estimate apply only to these overhauls.

total cost should also rise by 1 percent. Age was added to the regression equation because it was felt that older submarines are likely to need more work during overhauls than newer submarines.

Cumulative output (X) is expected to have a negative effect on cost because of learning by shipyard workers. The more overhauls a shipyard has performed, the better acquainted its workers are with the type of work involved and so the less future overhauls should cost. There are other variables that might also influence cost, such as changing technology and changes in the Navy's policy concerning the amount of work required in an overhaul. We could not measure these variables directly, but we assumed that some portion of them changes steadily over time, and used time as a variable to capture this portion.

Finally, Y was included in the regression equation to allow us to determine whether, when <u>all</u> relevant variables are controlled for, production costs are higher in public than in private shipyards. The coefficient of Y is an indicator of the relative efficiency of public yards.

The data which was used for input prices has already been described; the exact definitions of A, T, X, and Y are given in the appendix. The choice of data to represent output is discussed below. Since only 61 observations were available, we began by analyzing all three types of overhaul together.

In the empirical work, output was defined as the number of overhauls. Two complications arose with this definition. First, the three types of overhaul are sufficiently different from one another that it would be inappropriate to treat them as equivalent, yet there are not enough observations to estimate separate cost functions for each type. It was therefore felt that a multi-product cost function should be used, with three outputs: Q_1 = reqular overhauls, Q_2 = refueling overhauls, Q_3 = SRAs. This led to problems regarding the choice of functional form for the cost function, which will be discussed more fully below.

The second complication involved with defining output as the number of overhauls is that our unit of observation is one overhaul. This implies that the variables Q_1, Q_2, and Q_3 are, for our sample, equivalent to dummy variables for the type of overhaul, and one of them must be omitted from the regression equation if a constant term is included.

This ends the description of the variables included in the regression equations and the data used to represent the variables. In order to complete the discussion of the estimation procedure, we now describe the functional form chosen for the cost function.

FUNCTIONAL FORM

The simplest functional form conventionally used for production and cost functions is the Cobb-Douglas. This form has been used in previous shipbuilding studies ([9], [15]). The disadvantage of the Cobb-Douglas from a theoretical point of view is that it places restrictions on certain elasticities, while more flexible functional forms such as the translog do not. However, the Cobb-Douglas is much easier to estimate than the usual alternative functional forms; accordingly, this was the form we used.

A problem was encountered in trying to formulate the multiproduct cost function. There is a multioutput Cobb-Douglas production function, but it has undesirable properties (see [10], pp. 253-54); for example, the transformation curves between pairs of outputs are convex. In order to avoid using more complicated functional forms, we made a simplifying assumption about the relationship among regular overhauls, refueling overhauls, and SRAs.

Specifically, we assumed that all three types of overhaul involve essentially the same kind of work but in different amounts. That is, with given quantities of capital, labor, and materials a shipyard could accomplish X percent of a regular overhaul or y percent of a refueling overhaul or Z percent of an SRA. If this is true, then the transformation surface among the three types of overhaul will be a plane, and the cost function may be expressed as

$$C = e^{\beta_0} p_L^{\beta_1} p_K^{\beta_2} p_M^{\beta_3} X^{\beta_4} e^{(\beta_5 A+\beta_6 T+\beta_7 Y+\beta_8 Q_1+\beta_9 Q_2+\beta_{10} Q_3)} \quad . \tag{1}$$

Taking logs, subtracting $\ln p_M$ to insure linear homogeneity in input prices, and omitting Q_2 because of the dummy variable problem gives the estimating equation

$$\begin{aligned} \ln(C/p_M) = \beta_0 + \beta_1 \ln(p_L/p_M) + \beta_2 \ln(p_K/p_M) + \beta_4 \ln X \\ + \beta_5 A + \beta_6 T + \beta_7 Y + \beta_8 Q_1 + \beta_{10} Q_3 \ . \end{aligned} \tag{2}$$

In the next section of the paper, the regression results for (2) will first be presented and then be used to compare production costs and efficiency in public and private shipyards.

RESULTS

Table 7 gives the coefficients and t-statistics obtained by running ordinary least squares on various specifications of (2). Equations 1 and 2 are estimates of (2) using alternate definitions of the price of capital. Both these equations explain a high percentage (97 percent) of the variation in the dependent variable. In equations 3 and 4, (2) is estimated using only the data for regular and refueling overhauls, the two types of overhaul that were done in both public and private shipyards. The fit here is not quite as good.

Several patterns are evident in table 7. Cumulative output, age, and time come in strongly with coefficients that are generally significantly different from zero and relatively stable across equations. The coefficients of cumulative output and age have the expected signs. The coefficient of time is positive. This is inconsistent with the hypothesis that technological change (which lowers costs) has occurred over time, but other possible explanations include the following:

(a) The definition of an overhaul has expanded over time, so that a given type of overhaul requires more work now than it did several years ago.

(b) Regulation of shipyard activities by agencies such as EPA and OSHA has been increasing over time. Such regulation will raise measured costs if, for example, inputs which are used to comply with regulations are reported as being used to produce overhauls.

We have no direct evidence that (a) is true*, but it does seem likely that regulation has increased the cost of overhauls over time ([24], p. 62.)

The coefficients on input prices are disappointing. While we expect them to be positive, in our equations they are sometimes negative and never significant. Moreover, they vary widely across equations. This may indicate that the Cobb-Douglas functional form is an inappropriate representation of overhaul technology. This possibility could be investigated in future work by reestimating the cost function using other functional forms.

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*See, for example, [12], p. 81.

TABLE 7

REGRESSION RESULTS

Dependent Variable: $\ln(C/p_M)$

Equation No.	No. of Obs.	$\ln(p_L/p_M)$	$\ln(c/p_M)$	$\ln(r/p_M)$	$\ln X$	A	T	Y	Q_1	Q_3	Adjusted $\bar{R}^2$
		Coefficient (t-value)									
1	61	.131 (.38)	.274 (.63)		-.101* (-1.95)	.00422* (3.28)	.0629* (2.72)	.145 (.74)	-.187* (-2.14)	-2.689* (-29.47)	.97
2	61	.264 (.81)		-.136 (-.31)	-.096* (-1.86)	.00438* (3.28)	.0566* (1.88)	.014 (.08)	-.169* (-1.80)	-2.669* (-26.59)	.97
3	40	-.280 (-.87)	.590 (1.50)		-.131* (-2.90)	.00592* (1.70)	.0567* (2.31)	.349* (2.03)	-.142 (-.92)		.74
4	40	-.085 (-.26)		.123 (.29)	-.129* (-2.76)	.00594 (1.52)	.0626* (1.88)	.181 (1.11)	-.134 (-.81)		.72

*Significant at the 10 percent level.

The coefficients on the output variables are also not very strong, except in equations 1 and 2. These coefficients do, however, generally have the expected sign.*

The coefficient of Y is of interest for this study because it indicates the relative efficiency of production in naval shipyards. This coefficient will be discussed in detail in a later section.

The results in table 7 were used to answer two questions: whether production costs differ in public and private shipyards and why these costs differ. The next two sections explain how these answers were obtained.

PRODUCTION COST DIFFERENCES

One question which is undoubtedly of interest to Congress when deciding whether to assign overhauls to naval or private shipyards is where the work can be done most cheaply. We used the coefficients from equation 3 in table 7 to answer this question.**

Two sets of cost predictions were made. First, costs were estimated for each shipyard in the sample, holding age, year, and type of overhaul constant but using actual input prices and overhaul experience. Predicted costs for five of the shipyards (based on the sample average for A) are shown in table 8.

To control for interregional wage differences, separate comparisons of cost were made for naval and private shipyards in the same geographical area. The results of these comparisons are given in table 9.*** Statistical tests indicated that the differences in predicted cost between public and private yards in the same region were generally not significant at the 10% level.

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*We expect the coefficients of Q_1 and Q_3 to be negative since they involve comparing the cost of a regular overhaul or an SRA with the cost of a refueling overhaul.

**Despite the lower R^2 for the equations using the data for regular and refueling overhauls only, we have some preference for this formulation. It can be argued that SRA's are qualitatively different from the other types of overhaul due to the type and amount of work involved.

***Due to the form of (1) the predicted cost ratios are the same for any given age of submarine or type of overhaul.

TABLE 8

PREDICTED COST OF A REGULAR OVERHAUL USING
ACTUAL OVERHAUL EXPERIENCE ($000)

	Public shipyards			Private shipyards	
	Norfolk	Charleston	Portsmouth	Newport News	Electric Boat
1972	19,446	19,212	16,696	16,266	14,913
1973	19,435	21,025	17,682	17,748	15,251
1974	21,745	22,342	19,896	21,920	18,161
1975	25,978	27,464	24,326	28,151	23,672
1976	28,834	28,851	27,928	29,529	25,893
1977	30,884	30,646	29,505	30,044	27,526
1978	35,217	35,367	34,800	35,188	32,211

TABLE 9

PREDICTED COST RATIOS
BASED ON ACTUAL OVERHAUL EXPERIENCE

	Norfolk / Newport News	Charleston / Newport News	Portsmouth / Electric Boat
1972	1.195	1.181	1.120
1973	1.095	1.185	1.159
1974	.992	1.019	1.096
1975	.923	.976	1.028
1976	.976	.977	1.079
1977	1.028	1.020	1.072
1978	1.001	1.005	1.080

It was noted that most overhauls in our sample were done in naval shipyards. If the Navy changed its policy and assigned more overhauls to private yards, their costs would be even lower. To estimate the effect of such a change in policy, a second set of cost predictions was made, assuming the same level of overhaul experience for public and private shipyards. The resulting cost comparisons are given in table 10. Under these assumptions, predicted costs were always higher for naval shipyards than for private yards in the same region. Moreover, the differences in predicted costs were statistically significant.

TABLE 10

PREDICTED COST RATIOS ASSUMING EQUAL OVERHAUL EXPERIENCE FOR ALL SHIPYARDS

	Norfolk / Newport News	Charleston / Newport News	Portsmouth / Newport News
1972	1.195	1.181	1.181
1973	1.199	1.185	1.204
1974	1.145	1.116	1.155
1975	1.167	1.126	1.143
1976	1.171	1.128	1.165
1977	1.218	1.178	1.215
1978	1.224	1.177	1.224

We concluded that, controlling for previous overhaul experience, overhauls of the Sturgeon class of nuclear submarines during the 1970s cost more in naval shipyards than in private shipyards. In the next section, some possible reasons for this difference in costs are presented.

REASONS FOR DIFFERENCES IN PRODUCTION COSTS

In order to design policies that will lower production costs in naval shipyards, it is necessary to know why their costs are higher than those of private yards. Three potential differences between naval and private shipyards are discussed in this section. We do not attempt to measure the precise contributions of these differences to the difference in overhaul costs.

Differences in Input Prices

The higher input prices are, ceteris paribus, the higher the expected cost of an overhaul. In our data, wage rates were higher and the cost of capital was lower in naval shipyards than in private yards, while the price of materials was (by assumption) the same in both types of yard. Since shipyard work is labor-intensive, these differences in input prices are probably part of the explanation for the higher cost of overhauls in naval shipyards.

Differences in Overhaul Quality

In the statistical analysis, it was assumed that all overhauls of a given type are of equal quality. But it may be that naval shipyards do better work than private shipyards do. It is difficult to test this proposition because there is no really good measure of the quality of an overhaul.

One possible proxy for overhaul quality is the submarine's material condition after overhaul. We considered three measures of material condition:

(a) hours of maintenance downtime listed in Casualty Reports, or CASREPs;

(b) hours that the ship's force spent repairing the submarine; and

(c) hours spent in Intermediate Level Maintenance Activity (IMA hours).

We assume that the higher any one of these measures is, the lower the quality of the preceding overhaul.

Table 11 gives averages of the three measures for the 10 months after overhaul. The results are inconclusive. For regular overhauls, CASREP and IMA hours are lower for submarines overhauled in naval shipyards, but ship's force hours are higher. For refueling overhauls, both IMA and ship's force hours are higher for submarines overhauled in naval yards.

Thus, no strong conclusion emerges about the quality of naval versus private overhauls. More work is needed to determine whether there really is a difference in quality. For example, material condition probably depends on variables besides overhaul quality, such as the submarine's activity after overhaul. When comparing maintenance hours, it would be desirable to control for differences in these variables.

TABLE 11

MEASURES OF MATERIAL CONDITION
AFTER OVERHAUL

		Regular	Refueling
• CASREP maintenance downtime (hours)			
	Naval	754	942
	Private	890	1,197
• Ship's force hours			
	Naval	261	140
	Private	227	82
• IMA hours			
	Naval	1,365	500
	Private	1,591	81

Differences in Efficiency

Even though naval shipyard managers appear to face different input prices than private shipyard managers do, it is still possible for naval yards to be run efficiently. Efficiency requires that the combination of factors used to produce the desired output is the cheapest one possible.

In order to determine the relative efficiency of naval shipyards, it is necessary to predict overhaul costs holding factor prices as well as other relevant variables constant. If input prices and output are the same for public and private yards, then costs will be higher for the public yards only if they are using more resources to produce the same output.

In the empirical work, the coefficient of Y represents the percentage difference in the cost of an overhaul in a naval shipyard, holding all variables except for the type of shipyard constant. If this coefficient is positive and significant, we would not reject the hypothesis that overhaul production is less efficient in naval shipyards than in private shipyards.* Turning back to table 7, we see that the estimated coefficient of Y was positive in each of the four regression equations; however, it was not always significant. Moreover, its value varied widely across equations from 1.4 percent to 34.9 percent. In the equation in which the coefficient of Y was statistically significant, the implication is that inefficiency in naval yards raised the cost of overhauls by about 35 percent.

Because of the variation in the magnitude and significance of the Y coefficient, we do not want to place too much emphasis on any one estimate of the degree of relative efficiency. Nevertheless, we feel that there is some evidence to support the conclusion that naval shipyards were less efficient than private shipyards at doing overhauls of the Sturgeon class of nuclear submarines during the 1970s.

It should be kept in mind that the question which we have attempted to answer is whether public shipyards are more or less efficient than private shipyards. Finding that private shipyards are relatively more efficient does not necessarily indicate that they are efficient in an absolute sense. Moreover, our method does not allow us to determine whether the relative inefficiency of naval shipyards is technical or allocative--that is, whether it arises from the wasting of factors or from using factors in the wrong proportions.

DIFFERENCES IN OVERHAUL TIME

So far this report has focused on differences in the cost of overhauls, where cost is defined as the value of the manhours, machine hours, and materials used to perform an overhaul. Another aspect of cost concerns the length of time spent in overhaul. The longer a submarine is in overhaul, the less it is available for duty and so the lower the Navy's state of readiness.

*That is, we are attributing the entire "unexplained" difference in overhaul costs between naval and private shipyards to a difference in efficiency. This interpretation is consistent with the stochastic production function approach (see [1]) but is open to the objection that omitted variables are responsible for part of the difference in costs.

As a first approach to determining whether the time spent in overhaul differs in Naval and private shipyards, we computed the average length of the overhauls in our sample. The results are shown in table 12. The table indicates that regular overhauls took 12% longer and refueling overhauls took 16% longer in private shipyards. These differences are statistically significant.

TABLE 12

AVERAGE LENGTH OF OVERHAUL (DAYS)

	Regular	Refueling	SRA
Naval	355	525	60
Private	399	606	--

We have not integrated the analysis of overhaul time with the analysis of overhaul production costs. Further work is needed to determine

(a) why overhauls take longer in private shipyards;

(b) the cost of the extra time spent in overhaul in private yards; and

(c) how much it would cost to speed up overhauls in private yards.

The goal is to be able to compare the total costs--production cost plus time cost--of overhauls in the two types of shipyard. One approach to calculating (b) would involve computing how many more submarines would be needed to achieve a given level of readiness if overhauls were done in private rather than public shipyards.

CONCLUSION

This study investigated whether production costs differ in public and private shipyards, using data for overhauls of the Sturgeon class of nuclear attack submarines between 1971 and 1979. We proceeded by estimating a cost function and using the regression coefficients to predict costs in public and private yards holding the relevant variables constant. While the data has some limitations and the regression results were not uniformly good, we feel there is evidence that, for the type of work studied, production costs were higher in naval shipyards than in private shipyards.

Among the likely reasons for the difference in overhaul costs are (a) higher wages and (b) lower efficiency in naval shipyards. There may also be a difference in overhaul quality, but such a difference did not show up in the measures of material condition that we examined.

One difference that did emerge strongly was in the length of time per overhual, which was significantly lower in naval shipyards. When determining whether to assign overhauls to public or private shipyards, the Navy must decide whether the higher production cost of overhauls in Naval yards is outweighed by the lower time cost of those overhauls.

Because this study dealt with only one type of shipyard work, we do not feel justified in drawing general conclusions about naval shipyard efficiency. Analysis of other types of overhauls* as well as ship construction work would also be necessary in order to get a general picture of relative efficiency and how it has changed over time. The cost function approach employed here appears useful for this type of analysis. In future work, it would be desirable to experiment with more flexible functional forms than the Cobb-Douglas and also to try to decompose inefficiency into its technical and allocative components.

*Apparently, data on overhauls of all types of naval vessels is available from PERA.

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APPENDIX A

DATA SOURCES

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DATA SOURCES

I. Cost of Capital

r: For public shipyards, r = the average yield on all outstanding bonds due or callable in 10 years or more (from [14]). For private shipyards, r = the composite average of yields on industrial bonds (from [13]).

q: q_s = the implicit price deflator for structures, and q_E = the implicit price deflator for producers' durable equipment (both from [18]).

δ: δ was assumed to equal 2.3/T, where T is the useful service life of the asset (see [11]). The allowed service life for tax purposes (from [22]) was used as a proxy for the useful service life.

k: k = 0, .07, or .10, depending on the time period. k,u, and z were calculated using information in [4].

u: u = .48.

z: z depends on: the depreciation methods allowed for tax purposes; r; and T.

II. Independent Variables in the Cost Equation

A: the age of the submarine at the beginning of the overhaul, in months.

T: T represents the year in which the overhaul began (1 for 1971, ..., 9 for 1979).

X: the number of overhauls done at the shipyard, including the present one. For the purposes of constructing X, each overhaul counted as one unit, regardless of type.

Y: Y = 1 if the overhual was done in a naval shipyard; = 0 if done at a private yard.